Rotary spading and mouldboard ploughing water repellent sandplain soil fulfils promise

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Purpose:	To assess the impact of full inversion mouldboard ploughing and partial inversion rotary spading on soil water repellence, crop growth and grain yield using large scale on-farm trials.
Location:	Various locations in the Northern Ag Region, WA

KEY MESSAGES

1. Both rotary spading and mouldboard ploughing successfully overcame water repellence and both resulted in large grain yield increases mostly in the order of 500-1200 kg/ha.

2. Spading and ploughing of water repellent sandplain soils that have reasonable subsoil water holding capacity is more beneficial than for the pale deep sands whose low water holding capacity limits the opportunity to realise the improved yield potential, particularly in seasons with a dry finish.

BACKGROUND

In 2010 numerous growers in the Northern Agricultural Region implemented on-farm trials to test the value of one-off rotary spading or mouldboard ploughing of water repellent sandplain soils (Table 1). A number of these trials were selected and assessed to measure the impact of these tools on soil water repellence, crop growth and yield.

Table 1. *Details of on-farm rotary spader and mouldboard plough trials that were monitored in 2010.*

Grower	Location	Soil Type	Treatment Type	Year Treated	2010 Crop	Sowing Date	Growing Season Rainfall (mm)
Harris	Binnu	Yellow deep sand	Spader	2010	Magenta wheat	23-May	165
O'Callaghan	Marchagee	Yellow loamy sand	Spader	2010	Magenta wheat	22-May	177
Hayes	Warradarge	Pale deep sand	Spader	2010	Mace wheat	7-Jun	241
Hayes	Badgingarra	Pale deep sand	Spader	2009	Magenta wheat	15-May	218
McTaggart	W. Moora	Sand over gravel	Spader	2010	Calingiri wheat	31-May	220
Smart	E. Nabawa	Yellow loamy sand	Mouldboard	2010	Wyalkatchem wheat	25-May	211
Fordham	Badgingarra	Brown deep sand	Mouldboard	2010	Wyalkatchem wheat	15-Jun	270
Kenny	Badgingarra	Sand over gravel	Mouldboard	2010	Calingiri wheat	15-Jun	300
Kenny	Badgingarra	Pale deep sand	Mouldboard	2010	Baudin barley	14-Jun	300

TRIAL DESIGN

The implements used were 4-metre wide rotary spaders with working depths of 25-30 cm or 7-9 furrow one-way or reversible mouldboard ploughs with working depths of 30-35 cm. In most instances the trials were grower-scale unreplicated strip trials with untreated control crops either side of the treatment strips. In most cases the strips were wide enough to accommodate header cuts and ranged from 500 to 1500 m long. The Fordham site was an across fence comparison between two paddocks that used to be a single paddock before a laneway split the paddock into two. The soil type, position in the landscape, rotation and sowing details were the same for both paddocks. For all the strip trial sites establishment counts and sampling for soil analyses, crop biomass and yield were all conducted at paired sampling sites to account for soil variation. Comparison locations were targeted in those parts of the paddock most strongly exhibiting water repellence as the primary aim was to assess the capacity of the tools to overcome water repellence. Samples for water repellence testing were collected from 0-5 cm. Dried samples were assessed for water droplet penetration time (WDPT) under standardised laboratory conditions. Hand-harvest cuts were taken at crop maturity with crops harvested at ground-level so measures of above-ground biomass, head numbers, grain yield, harvest index and grain quality could be measured. Where available, yield monitor data from the header was collected on and off the treated strip as a measure of machine harvest yield. The soil types in this group of trials fell into two broad groups. One group was the highly repellent pale, yellow and brown deep sands with low clay content to depth (typically <5%) and very poor water holding capacity. The other group includes soils with highly repellent sandy topsoils but with reasonable subsoil water holding capacity. This included the yellow loamy sands (also known as sandy earths) whose subsoil clay contents of ~5-10% and the sand over gravel soils with subsoil having high gravel content typically in a loamy or clayey soil matrix.

RESULTS

Mouldboard ploughing and rotary spading were both successful at improving crop establishment. In untreated control areas establishment was staggered and due to the lengthy periods between rains at the break of the season many plants established quite late. By comparison ploughing or spading resulted in even establishment at the break of the season (data not shown). We used water droplet penetration time (WDPT) to compare the water repellence of the control and soil inversion treatment at each site. The control treatments had severe water repellence with WDPT exceeding 600 seconds (10 minutes) at all the sites apart from a loamy sand site at Marchagee (WDPT = 182 secs, moderate repellence; Table 2). The water repellence of the spader and mouldboard treatments was variable, ranging from 2 to > 600 seconds.

Table 2. *Impact of rotary spading or mouldboard ploughing on water droplet penetration time (WDPT; seconds) for 0-5 cm soil samples for selected on-farm trial sites.*

Grower (Crop)	Location	Soil Type	Treatment Type	Year treated	WDPT Control	WDPT Treated
Harris (wheat)	Binnu	Yellow deep sand	Spader	2010	>600	470
O'Callaghan (wheat)	Marchagee	Yellow loamy sand	Spader	2010	182	5
Hayes (wheat)	Warradarge	Pale deep sand	Spader	2010	>600	418
Hayes (wheat)*	Badgingarra	Pale deep sand	Spader	2009	>600	8
Smart (wheat)	E. Nabawa	Yellow loamy sand	Mouldboard	2010	>600	2
Fordham (wheat)	Badgingarra	Brown deep sand	Mouldboard	2010	>600	>600
Kenny (barley)	Badgingarra	Pale deep sand	Mouldboard	2010	>600	38

Spading tends to have higher WDPT than mouldboard ploughing as spading leaves some topsoil near the surface. Mouldboard ploughing usually results in very low WDPT measures except in those cases where the soil conditions (too dry) or plough setup results in incomplete inversion. The Fordham site is an example of this. The site has a very deep organically stained topsoil layer and the plough struggled to invert this however crop establishment and productivity was still much improved at this site (Table 4). Lower WDPT measures are also achieved on soils that have higher clay contents in the subsurface soil, such as the loamy sands at the O'Callaghan and Smart sites

(Table 2). The clay brought to the surface through inversion on these soils further aids soil wettability. For example, at the O'Callaghan site the spading increased clay content of the topsoil from 4.6 to 6.2%.

Both of these tillage tools alter nutrient distribution in the soil profile. The partial inversion achieved by spading means that the changes in nutrient distribution through the soil profile are not as dramatic as occurs with the full inversion achieved using mouldboard ploughing. On the pale deep sand at Kenny's mouldboard ploughing resulted in significant redistribution of, organic carbon, nitrogen, phosphorous and potassium out of the top 0-10 cm layer into the 10-30 cm layer (Fig. 1). Increased N mineralisation of the inverted organic matter as a result of increased aeration and soil moisture is the likely reason for the spike in nitrate at depth (10-30 cm) after mouldboard ploughing (Fig.1). The redistribution of phosphorus where Colwell P in the 0-10 cm layer was reduced from 20 mg/kg to 6 mg/kg by mouldboard ploughing (Fig. 1) is also likely to impact on crop growth.

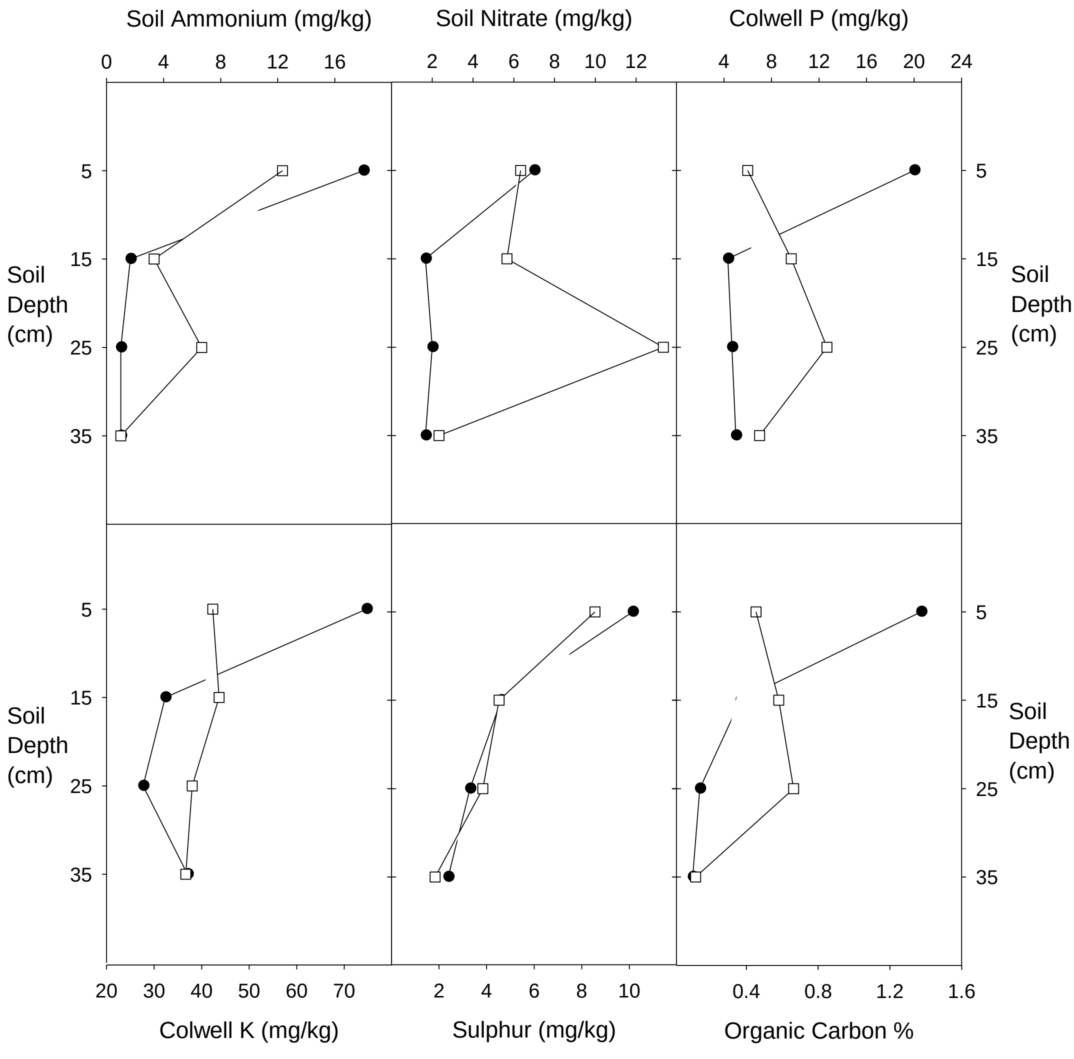

Figure 1. *Impact of soil inversion on soil nutrient and organic carbon distribution in a pale deep sand profile at Badgingarra (Kenny's) in 2010 following a long-term blue-lupin pasture.*

Table 3. *Effect of rotary spading (Spade) of water repellent sandplain soils on cereal crop biomass, yield components and grain quality in 2010 compared with an untreated control (Nil).*

Grower (Crop)	Location	Soil Type	Shoot biomass (t/ha)		Head number (heads/m^2)		Grain yield (t/ha)		Harvest Index		Kernel Weight (mg)		Screenings (%)		Protein (%)	
			Nil	Spade	Nil	Spade	Nil	Spade	Nil	Spade	Nil	Spade	Nil	Spad e	Nil	Spade
Harris (wheat)	Binnu	Yellow deep sand	3.0	5.0	142	252	1.2	1.9	0.40	0.38	31.0	32.3	3.4	5.0	12.2	11.4
O'Callaghan (wheat)	Marchagee	Yellow loamy sand	5.6	8.0	243	309	2.4	3.5	0.43	0.43	39.1	36.2	1.7	3.0	10.5	11.3
McTaggart (wheat)	West Moora	Pale sand over gravel	3.4	7.3	175	248	1.4	3.4	0.41	0.47	36.3	43.1	2.6	0.3	12.7	10.8
Hayes (wheat)	Warradarge	Pale deep sand	2.2	4.3	161	348	0.7	1.1	0.29	0.25	16.4	12.8	22.0	48.2	18.5	17.9
Hayes (wheat)*	Badgingarra	Pale deep sand	1.9	3.1	146	249	0.5	1.0	0.29	0.31	18.7	20.7	27.1	24.9	17.3	15.7

* This site was rotary spaded in 2009 so this represents a second year response to spading.

Table 4. *Effect of mouldboard ploughing of water repellent sandplain soils on cereal crop biomass, yield components and grain quality in 2010 compared with an untreated control (Nil).*

Grower (Crop)	Location	Soil Type	Shoot biomass (t/ha)		Head number (heads/m^2)		Grain yield (t/ha)		Harvest Index		Kernel Weight (mg)		Screenings (%)		Protein (%)	
			Nil	Plough	Nil	Plough	Nil	Plough	Nil	Plough	Nil	Plough	Nil	Plough	Nil	Plough
Kenny (wheat)	Badgingarra	Pale sand over gravel	2.3	4.6	146	207	1.0	2.2	0.40	0.46	29.1	36.0	11.4	5.2	16.4	15.0
Smart (wheat)	East Nabawa	Yellow loamy sand	3.5	4.7	201	277	1.4	1.9	0.39	0.41	28.2	28.7	7.3	6.1	13.0	14.3
Fordham (wheat)	Badgingarra	Brown deep sand	1.1	2.7	98	165	0.5	1.0	0.44	0.35	29.6	29.6	3.9	6.0	12.8	14.9
Kenny (barley)	Badgingarra	Pale deep sand	1.5	4.8	212	507	0.8	2.0	0.61	0.42	-	-	-	-		

Substantial biomass and grain yield increases were seen at all the sites (Tables 3 and 4). Mature shoot biomass was increased by both spading and mouldboard ploughing by an average of 2 t/ha, and there was an average increase of over 100 heads/m^2 as a result of the use of these soil inversion treatments (Tables 3 and 4). These results are largely a result of improved (earlier) and more even establishment resulting in more dense crops, which was particularly evident on the most severely water repellent deep sands, such as the Hayes site at Warradarge (Table 3) and the Kenny barley site (Table 4).

On average grain yield was increased by over 800 kg/ha for both treatments but there was significant variation between soil types. The yield response of wheat on the deep pale and coloured sands was around 400-700 kg/ha (Fig. 2) whereas on soil with water repellent topsoil but reasonable water holding capacity subsoil the yield responses tended to be higher with all but the Smart site having increases of 1000 kg/ha or more (Fig. 2). This result isn't surprising given that all the sites experienced a dry finish to the season and the deep sands would have had little stored water for grain filling and are prone to haying off.

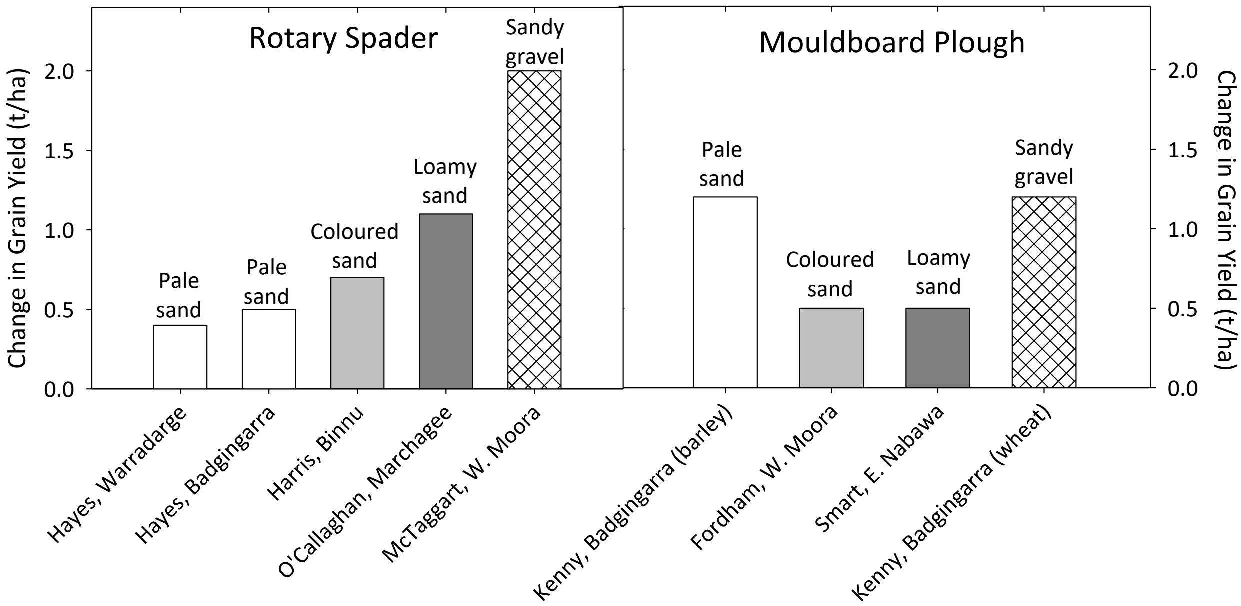

Figure 2*. Average change in grain yield in response to rotary spading or mouldboard ploughing for a number of on-farm field trials conducted in 2010 across a variety of sandplain soil types. Data are for wheat unless otherwise indicated.*

While removing the non-wetting constraint usually leads to higher grain yields it can increase the risk of haying off. The Hayes' Warradarge site is a good example of this, rotary spading lead to an increase of crop biomass at maturity of 2.1 t/ha yet grain yield only increased by 0.4 t/ha with a large increase in screenings and a small decline in the harvest index (Table 2).

DISCUSSION

Yield response to amelioration

There are many possible factors that may be resulting in the large grain yield responses measured after using these tillage tools including:

- reduced water repellence;
- improved and earlier (more even) crop emergence;
- improvements in the pH profile through burial of higher pH topsoil and lifting of low pH subsoil and incorporation of surface applied lime;

- reduced soil strength through a soil loosening effect (deep ripping effect);
- reduced weed competition;
- changes in nutrient and organic carbon distribution;
- increased N mineralistion;
- reduced occurrence of stubble and soil-borne pest and disease;
- reduced carryover of residual herbicides in water repellent soil.

It is likely that the relative importance of these factors may vary from site to site and it may be difficult to determine which of these factors are the main drivers of the yield response in any given situation. Several of these factors, including the impacts of these techniques on pests and disease and carryover of residual herbicides, have received no research attention to date. At this stage use of both the spader and the mouldboard plough seem to result in similar yield increases in the first year.

Amelioration of water repellence on soils with good subsoil water holding capacity and hence higher yield potential will result in the highest yield gains. In all of the trials on the pale and weaker sands, spading or mouldboard ploughing resulted in a reduction in the harvest index and often increased screenings (Tables 3 and 4), indicative of the fact that the larger biomass crops on these soils with poor water holding capacity failed to fully meet their increased potential yield. On the pale sands trying to moderate the increase in shoot biomass using reduced seeding rates and lower post-seeding N applications may help to minimise the risk of haying off and compromised grain fill. The value of still treating these pale sands with these tools despite the lower potential yield gains is that at least the improved establishment results in better weed competition, a crop with reasonable yield potential and good stubble cover to reduce wind erosion risk over summer. This improved stubble cover may also aid water infiltration in following years.

Impact on soil water repellence

Both implements ameliorate water repellence. The mouldboard plough does this by completely inverting and burying the water repellent topsoil and bringing to the surface wettable topsoil. Rotary spading is different in that it does not evenly mix the subsoil and topsoil. Some clumps of topsoil tend to get moved to depth while seams of subsoil are lifted to the surface but there are still significant amounts of repellent topsoil near the surface. Overall approximately 2/3 of the topsoil is buried through spading with the remaining 1/3 being mixed through the topsoil. It was observed following reasonable rains after a mid-season dry spell in 2010 that the seams of subsoil created by spading provided many more preferential pathways for water entry into the spaded soil, so any additional mixing or homogenisation of these soils may destroy these preferred pathways and needs to be avoided or the benefits might be lost. Because of these different mechanisms it is suspected that amelioration of water repellence by mouldboard ploughing may last longer than the amelioration by spading but we have no data to confirm this yet.

Nutrition

The implication of the re-distribution of the organic matter and nutrient rich topsoil from the use of these implements varies for each of the nutrients. Both spading and mouldboard ploughing are likely to increase N mineralisation although this can vary due to a range of factors including the amount and type of stubble buried. Reduction of P levels in the surface soil may have a negative impact on crop growth because P is needed early for tiller production. Fertiliser strategies need to account for this. It should be remembered however, that while topsoil P concentrations may indicate the presence of adequate P in the control situation not all of this may be available in water repellent soils that remain dry for much of the growing season. The redistribution of K to depth poses less of a problem for crop growth because the crop can 'grow into' K in the 10-30 cm layer. This redistribution of nutrients highlights the need to conduct soil testing post-treatment including subsoil testing.

Which implement to choose

Deciding which of the implements is best to use comes down to each individual growers priorities and what they want to use the tools for. A mouldboard plough is the best tool if weed control is a high priority plus it is cheaper and faster to use but can require more technical skill to get the plough setup right and the inverted soil is very soft and will need to be rolled in a seperate operation. Previous research has shown that the spader can control 60-70% of the weeds compared with >90% for the mouldboard plough. The spader is the better tool for incorporating amendments, including clay-rich subsoil (claying) or lime into acid subsoils. Spading leaves some water repellent topsoil near the surface so emerging crops do have access to some soil nutrients, including P in the surface soil but it may also mean that water repellence can re-develop more rapidly on spaded soils compared with those inverted by the plough. Many growers and contractors prefer to deep rip the soil prior to spading to decrease the soil strength and remove rocks or stumps but this is an additional cost.

Costs

The cost of mouldboard ploughing can vary depending on size and efficiency of the plough used and also on whether costs such as depreciation, interest, fuel, wear-and-tear and labour, for example, are taken into account. Growers who own larger 9-14 furrow mouldboard ploughs generally put the cost at $70-100/ha while contract rates for mouldboard ploughing are generally in the order of $100-130/ha. A number of other mouldboard plough trials in the NAR have given yield responses at some sites 3 years after ploughing although several sites have also been unresponsive. Growers who have inverted entire paddocks always report that they have been able to reduce the number of herbicide applications they apply to the crop which is a further cost saving. Contract rates for rotary spading seem to be of the order of $120-150/ha but if the soil needs to be deep ripped prior to spading this may be higher. At this stage we only have evidence to show that at least 2 years of yield benefits are likely. While some weed control benefits will accrue form using a spader control is not likely to be enough to reduce the number of herbicide applications required.

Fitting spading and mouldboard ploughing into the system

Given the higher yields, improved weed control and reduced water repellence many growers are keen to undertake more rotary spading and mouldboard ploughing on their farms. The problems and concerns raised by growers in regards to the use of these tools are:

- Soil softness can result in poor trafficability in ploughed soils that haven't had adequate rolling the soil can be very soft even at harvest. Rolling the soil after mouldboard ploughing is a necessity.
- Many growers do not have access to tractors with 3-point linkage that have sufficient horsepower for these implements. This may be mitigated somewhat as tool carriers are available for mouldboard ploughs and more trailing spaders are becoming available.
- The high erosion risk associated with burying all soil cover is the only reason why some growers are not adopting large mouldboard ploughing or spading programs. It is not possible to remove this risk, it can only be minimised by ploughing or spading the soil when it is wet and sowing a cereal cover crop immediately.
- Timing of ploughing and spading is a huge constraint. Contractors are only likely to come at a growers preferred time if they have a large renovation program planned and the demand for contract ploughing and spading services is likely to grow. The cost of large renovation program may make purchasing a plough or spader more

attractive to a grower but then they may also need to purchase a suitable tractor and will need to find an operator at a time when there is competition from other seeding and spraying operations.

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